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2017 IOP Conf. Ser.: Mater. Sci. Eng. 203 012005

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Utilization of polyethylene terephthalate (PET) in bituminous mixture for improved performance of roads

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Abstract. Plastic bottle for recycling can be found from the household waste stream, and most of them are made from Polyethylene Terephthalate. In this research, PET is utilized to explore the potential prospects to upgrade asphalt mixture properties. The objectives include deciding the best measure of PET to be used. For experimental, Marshall mix design was utilized to determine the ideal bitumen binder content and to test the modified mixture properties. The samples were created per the requirement for aggregate course wearing (ACW14) using the Standard Specification of Road Work (SSRW) in Malaysia. 20 samples were utilized to determine the binder content, and 30 samples were used to research the impact of modifying asphalt mixtures. 2%, 5%, 10%, 15% and 20% of PET by weight of the optimum binder content (4.8%) were tested. Optimum PET content is 10%, and the result shows a good stability with 16.824kN, 2.32g/cm³ bulk density, void filled with bitumen (VFB) with 71.35%, flow with 3.2248mm, air void (AV) with 4.53%, and void of mineral aggregate (VMA) with 15.15%. The outcomes showed that PET modifier gives better engineering properties. Therefore, 10% of PET by the weight of binder content was suggested as the best amount of the modifier.

1. Introduction

As urbanization keeps its pace with a steady growth, waste management has turned into a noteworthy environmental issue around the world. Indeed, Malaysia is one of the biggest plastics makers in Asia, with more than 1,550 manufacturers, utilizes around 99,100 people, [1] is also facing the issue. Fast development of plastics industries in Asia's emerging markets particularly in Malaysia, in one way it raised expectations for everyday comforts, in the other way it also causes an environmental issue. This issue tends the government to bans on bags and another packaging. Restrictions of plastic packaging are being enacted or proposed over the continent, including in Philippines, India, and Malaysia. Due to the manufacturing of plastic which causes chemical plant pollution, worldwide assertive citizens protested its presence [2]. It is identified that plastic waste contamination in China alone is to hit 19.1million tons by 2017 [3]. This projection can also be used to predict the number of amounts of plastic waste in Malaysia for the same year. Recycling this plastic into another form might be one of the cheapest and rapid solutions.



Most of the road networks in Malaysia are flexible pavement design. The number of components (binder, aggregate and additive) in the mixture and the properties of it can influence the performance of flexible course. Bitumen can be altered by adding distinct sorts of additive [4]. Polymers are one of the additives which mainly having good attention to be used on earthwork and building construction field. PET is one of the polymers that vastly used to coat aggregates in asphalt mixtures. Coating ensures a proper bond between aggregates and improving its surface roughness for a good relationship thus makes superior engineering properties to asphalt mixtures [5, 6].

In this research, PET which is a type of plastomer was used to modify the properties of the asphalt mixture. It is used to coat the aggregate instead of changing the properties of bituminous. The primary objectives of this research are to study the effect on the hot mix asphalt when PET was added and to determine the optimum bitumen content and excellent PET content in the asphalt mixture.

2. Materials and method

Bituminous material: Asphalt binder 80/100 was used as the main mixture medium. Some laboratory tests have been carried out to determine the properties of the bitumen: Thin Film Oven, Penetration, Ductility, and Softening point. Table 1 shown the properties of asphalt binder, which are in a particular range of asphalt grade 80/100.

Aggregate properties: The laboratory tests performed on aggregates were: Los Angeles Abrasion, Aggregate Impact Value, and Aggregate Crushed Value. Table 2 shown the results of aggregate tests. Standard Specification of Road Work in Malaysia [7] used to define the mix gradation limits as shown in Table 3.

Polyethylene Terephthalate (PET): PET is an acronym for polyethylene terephthalate, which is a long-chain polymer belonging to the generic group of polyesters. Polyethylene Terephthalate (PET) is a semi-crystalline, thermoplastic polyester [8]. PET is one of the polyesters which formed by a polymerization reaction between an acid and alcohol [9]. PET is a polymer which easy to handle and also durable and sturdy, has low gas permeability, thermally stable and chemically [10]. For this research, plastic bottle which made by PET was used. The bottles were collected, and shred into small pieces about 2 mm to 5mm. Table 4 shows mechanical properties of PET.

Table 1. Properties of used asphalt binder

Test	Test Result	Specification	
		Min	Max
Ductility (cm)	150	100	-
Penetration (0.1mm)	86	80	100
Softening point (°C)	46.3	45	52
Thin Film Oven (% wt)	0.398	-	0.75

Table 2. Properties of used Aggregate

Test	Average % Loss
Los Angeles Abrasion	21.24
Aggregate Impact Value	21.55
10% Fine Aggregate	11.60
Aggregate Crushed Value	25.46

Table 3. Proposed mix gradation

% Passing	20 mm	14 mm	10 mm	5 mm	3.35 mm	1.18 mm	0.425 mm	0.15 mm	0.075 mm
Proposed Mix	100	95	81	56	47	26	18	10	6
Minimum Limit	100	90	76	50	40	18	12	6	4
Maximum Limit	100	100	86	62	54	34	24	14	8

Table 4. Mechanical Properties of PET [10]

Properties	Values
Average molecular weight	30000 - 80000 gmol ⁻¹
Density	1.41 gcm ⁻³
Melting temperature	255 - 265 °C
Glass transition temperature	69 - 155 °C
Young's modulus	1700 MPa
Water absorption (24 h)	0.5%

After determining the optimum bituminous material content (4.8% of mixture weight), five different proportion of PET (2%, 5%, 10%, 15% and 20% by weight of binder content) has been added to the asphalt mix. There are five samples for every PET portion.

Sample preparation: Determination of the right proportion of aggregate and asphalt can affect the performance of an asphalt mixture. 20 samples with 1116 grams each was prepared per the proposed mix design to determine the maximum bituminous content that would produce asphalt mixtures with strength and durability properties that meet the Standard Specification of Road Work in Malaysia. Three sample of each binder content proportion were used to prepared asphalt mix. After that, the average of unit weight, Marshall stability and flow properties for each binder content were determined. Seven binder contents were considered (4%, 4.5%, 5.0%, 5.5%, and 6.0%). The ACW14 suggests that the optimum bitumen content ought to obtain in a range of 3 to 5% air void, 70% to 80% void filled with bitumen and higher than 8000N of stability. From the experiment, the optimum bituminous content was 4.8%.

25 samples of asphalt mixtures were prepared with this binder content to test the effect of adding the PET to the mix. There are five proportions of the PET (2, 5, 10, 15, and 20%) which were added to these 25 samples. The samples were tested to determine the unit weight, stability and flow for each PET proportion. The aggregate of each specimen is heated until it reached 170° C before adding the PET. The duration and heating temperature were chosen based on literature review from reference [11]. This temperature is sufficiently hot to melt the PET with a particular size of 2 mm - 10 mm to such an extent that it would stick to the aggregate surfaces and leave a textured PET surface with a bond between the coated aggregates. The overall binder is assumed as 4.8% which same as optimum bitumen content. The weight of the overall binder is calculated as Eq. (1):

$$\%binder = \frac{Wb}{Wa + Wb} \quad (1)$$

Where

W_b is weight of binder

W_a is weight of aggregate

By using the formula, the weight of overall binder is 56.27g. The amount of bitumen decreases when the amount of PET increases, which to achieve 4.8% as the overall binder. Table 5 shows the proportion of the mix.

Table 5. Proportion of the modified asphalt mixture

Binder				
plastic		Bitumen		overall
%	g	%	g	g
2	1.13g	98	55.14g	56.27
5	2.81g	95	53.46g	
10	5.623g	90	50.64g	
15	8.44g	85	47.83g	
20	11.25g	80	45.02g	

3. Results

A comparison between conventional asphalt mixture (No PET) and PET asphalt mixture is presented below.

3.1. Bulk density- PET content relationships

The bulk density of the conventional asphalt mixture is higher than modified asphalt mixture. The bulk density of modified asphalt mixture reaches a maximum value when PET content is around 2%. The general trend shows that as the content of PET increased, the bulk density also increased. Figure 1 shows the bulk density of PET modified asphalt.

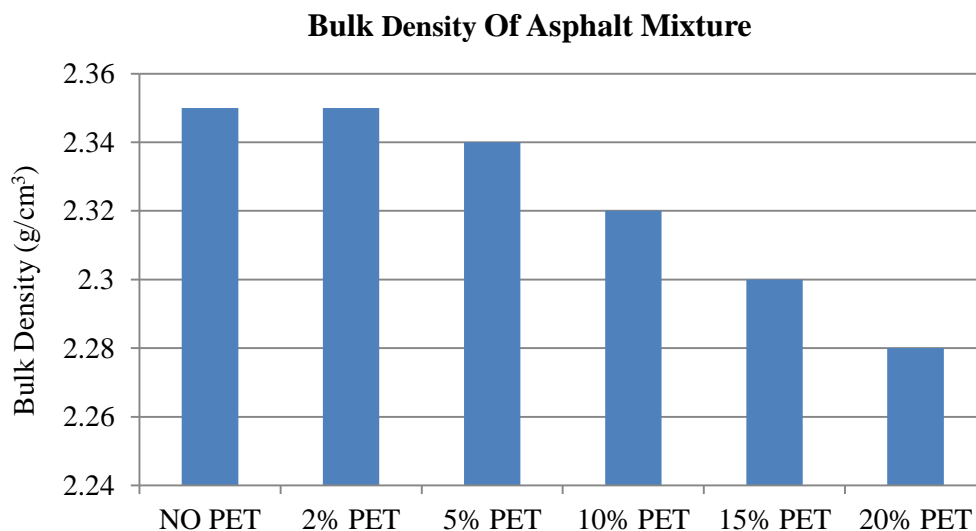


Figure 1. Bulk Density of PET Modified Asphalt

3.2. Stability- PET content relationship

The stability of the conventional asphalt mixture is lower than modified asphalt mixture. 18.359kN is the highest balance for asphalt mixture which was treated with 20% of PET. Figure 2 show the stability of modified asphalt mixture increase continuously by an increase of the modified content.

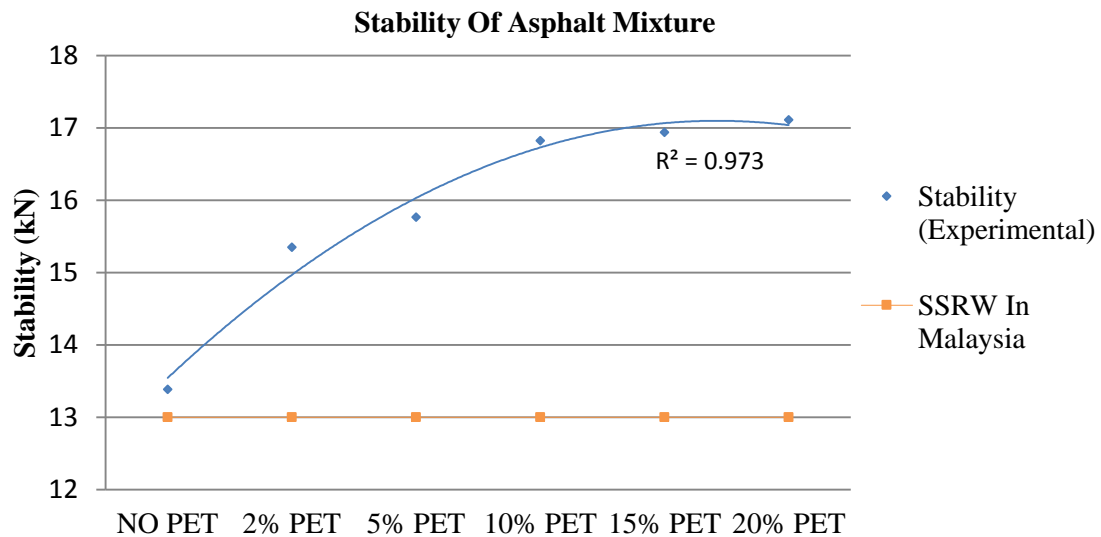


Figure 2. Stability of modified asphalt mixture

3.3. Flow- PET content relationship

The flow of the conventional asphalt mixture is lower than modified asphalt mixture. 3.374mm is the highest flow can be observed which treated with 20% PET. This value is still within the range of Standard Specification of Road Work in Malaysia. Figure 3 show that when the % of PET increased, the flow increased continuously.

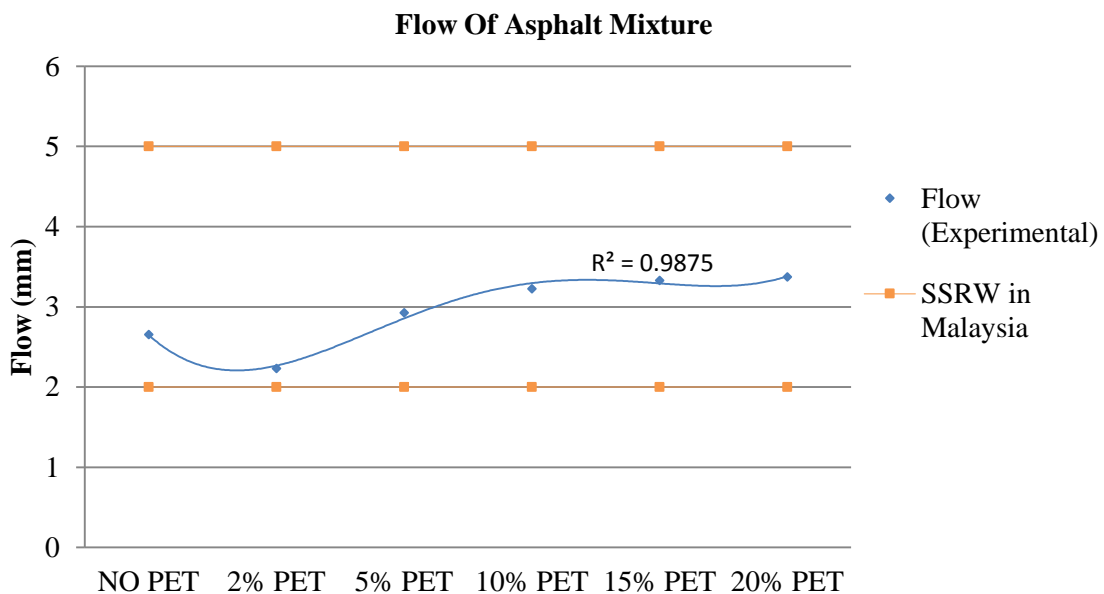


Figure 3. Flow of modified asphalt mixture

3.4. Air Void (AV) - PET content relationship

Air void is also known as void in the total mixture. From the experiment, the air void proportion of the conventional asphalt mixture is lower than modified asphalt mixture. The result of air void with PET content 15% and 20% exceeded the range of Standard Specification of Road Work in Malaysia. The only mixture with 2%, 5% and 10% of PET have achieved the specification. When the modifier content increased, it was found that the amount of air void was also increased (Figure 4).

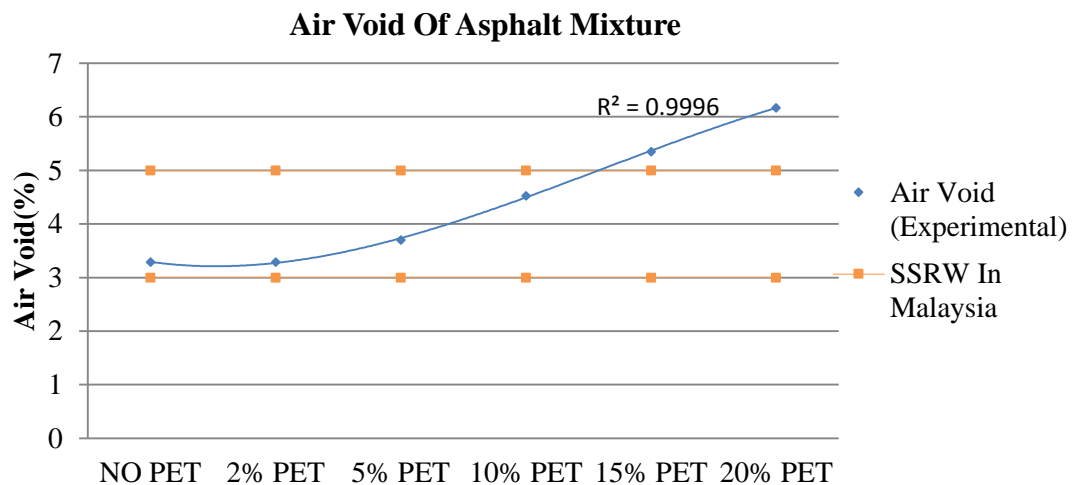


Figure 4. Air Void of modified asphalt mixture

3.5. Void filled with bitumen (VFB) - PET content relationship

In general, the VFB of conventional asphalt mixture is higher than a mixture with PET content. VFB of 15% and 20% PET content exceeded the Standard Specification of Road Work in Malaysia. The only mixture with 2%, 5%, and 10% of PET has achieved the specification. The content of VFB in modified asphalt mixture decreased when the amount of PET increased (Figure 5).

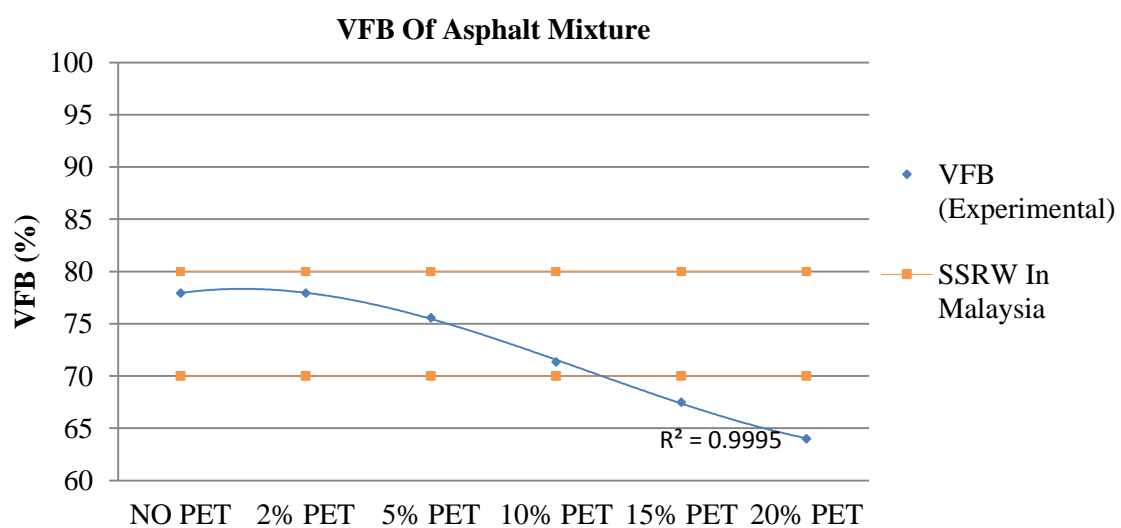


Figure 5. The amount of VFB in modified asphalt mixture

3.6. Void of mineral aggregate (VMA) - PET content relationship

VMA of conventional asphalt mixture is lower than modified asphalt mixture. The maximum of VMA is 16.61% at 20% of PET content. The trend shows that the VMA increased as the percent of PET increased. Figure 6 show the trend of VMA in modified asphalt content.

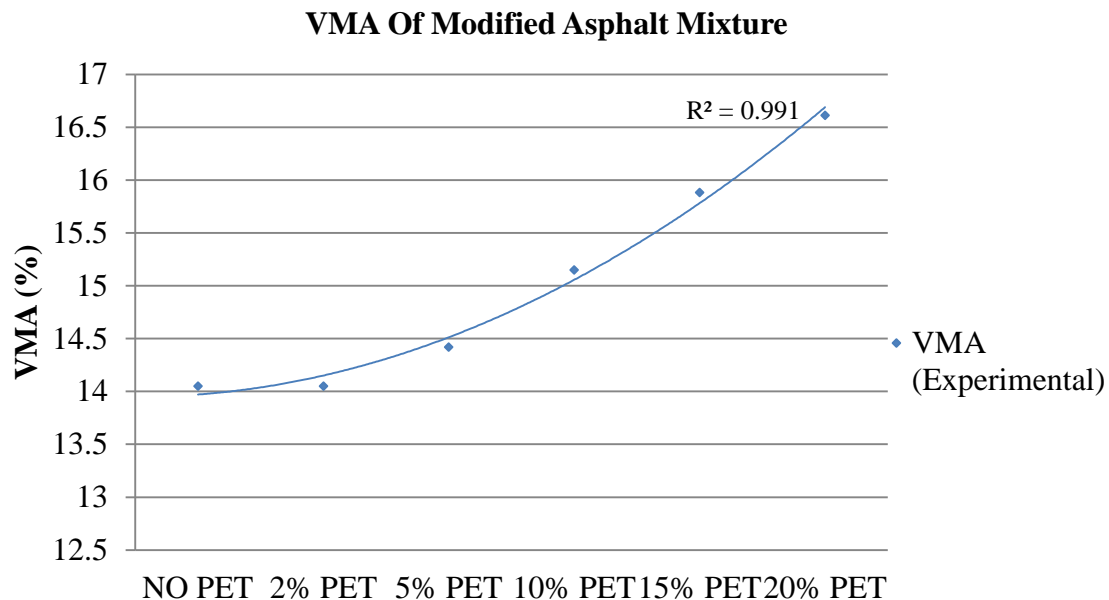


Figure 6. VMA in modified asphalt mixture.

3.7. Optimum Modifier Content

Based on research done by [12] asphalt mix with optimum modifier content should have maximum stability, maximum bulk density and percent of air voids within the allowed range of specifications. The procedures to obtain optimum modifier content is by plot the graph of Marshall properties which are graph stability versus modifier content, graph density versus modifier content, and graph voids in the total mix (VTM) versus modifier content. From the graphs, the optimum modifier content has been determined by finding the modifier content at maximum stability, maximum density, and Air Voids within the allowed range of specifications. The optimum modifier content was calculated as Eq (2) [12] and 4% of VTM is chosen because it is median of air voids range. The optimum modifier content is selected as the content that satisfies the Standard Specification of Road Work in Malaysia (table 6).

$$OMC = \frac{(MC \text{ max density}) + (MC \text{ max stability}) + (MC \text{ at 4\% of VTM})}{3} \quad (2)$$

Where

OMC is optimum modifier content

MC is modifier content

VTM is air voids of total mix

Table 6. Standard Specification of Road Work in Malaysia for ACW14

Parameter	Wearing Course
Stability, S	>13000N
Flow, F	2-5 mm
Stiffness, S/f	> 2600N/mm
Air voids in mix (VTM)	3-5%
Voids in aggregate filled with bitumen (VFB)	70-80%

From the calculation result, optimum modifier content was decided with 10% PET content. Since 10% PET content has satisfied the Standard Specification of Road Work in Malaysia.

4. Discussions

4.1. Stability

Based on the results of the study, the stability of modified mixture is higher compared to the non-modified mixture. This matter would positively have an impact on resistance and rutting of this mixture. When waste plastic is used in coating aggregate, it improved the stability of the asphalt mixture [13]. Besides that, utilization of plastic in the dry process (aggregate coating) can also minimize the susceptible rutting compared to conventional asphalt mixture. Rutting occurs due to weak shear strength to withstand continual heavy load and affect the performance in the pavement surface course. This problem makes the mixture accumulate and forming a rut characterized by a downward and lateral movement of the pavement [14]. By adding PET to the bituminous mixture, shear strength and stability will increase, and this can overcome the rutting problem.

Studies made by Mishra, B. and R.S. Mishra [15] show that waste plastic that added directly with hot aggregate can increase the stability of asphalt mixture and this result also achieved by Sridhar, Bose, Kumar, and Sharma on 2004 [16]. Vasudevan and his friends [6] also stated that this method was better compared to the wet process. In the wet process, polymer particles are added to the bitumen at a certain temperature to produce polymer modified binder. In the dry process, the polymer particles are added directly to coated aggregate before the binder is added to the mixture [17]. The bituminous mixture produced by the dry process has shown that the polymer does not swell during mixing period, transportation and laying. The rate of bitumen absorption by polymer is high which can make the residual bitumen elastic and stiffer, and this will change the rigidity of the polymer whereby effect the performance of the pavement [18].

4.2. Air Void

The proportion of air void can influence the performance of the asphalt mixture. This is because high air void can cause sensitive crack pavement because of asphalt oxidation or the water enter the voids which will cause striping of aggregate [19]. Air voids are pockets of air or little air spaces which can be found between the coated aggregate particles in the last compacted mixture. A particular amount of air void is needed in all dense-graded highway mixes to consider some additional pavement compaction under traffic activity and to give spaces into which little amount of asphalt can stream during this subsequent compaction [20]. Air void exceedingly related to the compaction to the mixture. Air void decreased when the small particles were filled with aggregate, and this happens when high compaction is applied. When shredded PET was added into the hot aggregate, it might not be entirely melted, and compaction may cause void whereby the aggregate is not filled by the particle properly.

PET will be not fully melted when the PET content was increased. Hence the aggregates cannot be coated properly. Besides that, the bitumen content was reduced as the PET content increased to achieve the amount of 4.8% binder content. This affected the bonding between aggregate and caused increasing of the void. 3% to 5% of air void were required to permit the additional compaction occurred because of traffic load. Lower voids in the mixture can cause bleeding to occur because the pavement cannot withstand extra load reacted on the mix surface.

4.3. Bulk Density

Density is one of the most important parameters in construction of asphalt mixtures. A good mixture contains enough air voids to prevent rutting due to plastic flow but low enough air voids to prevent permeability of air and water. Since density of an asphalt mixture varies throughout its life the voids must be low enough initially to prevent permeability of air and water and high enough after a few

years of traffic to prevent plastic flow. There are three primary methods of specifying density: percent of control strip, percent of laboratory density, and percent of theoretical maximum density. All three methods can be used to obtain satisfactory compaction if used correctly. Some effort construct a control test strip, measure the density on the strip, and use that density as the target density for the project [21]. Other efforts compact samples in the laboratory during mix design and during construction and use that density as the target density [22]. Finally, other efforts measure the theoretical maximum density (ASTM D 2041) and use some percentage of that density as the target density [23, 24]. The voids in an asphalt mixture are directly related to density; thus, density must be closely controlled to ensure that the voids stay within an acceptable range. High voids lead to permeability of water and air resulting in water damage, oxidation, gravelling, and cracking. Low voids lead to rutting and shoving of the asphalt mixture [25]. The acceptable range based on the Standard Specification of Road Work in Malaysia is between 3% to 5%.

5. Conclusions

The outcome from the lab testing shows that stability, flow, voids of mineral aggregates and air voids of modified asphalt mixture is higher than conventional asphalt mixture. The results also show that bulk density and void filled with bitumen of modified asphalt mixture is lower than conventional asphalt mixture. The optimum bitumen content is 4.8%, and excellent PET content is 10%. All the results uncover the modified asphalt mixture with 10% PET content is better than conventional asphalt mixture.

In term of economic value, utilization of recycled PET could reduce road construction cost because this material is not expensive compared to bitumen and it also easy to found. Therefore PET modified asphalt mixture can oppose the previously road failures. Additionally, it enhances the level of performance and the lifespan of the road. In conclusion, utilization of PET in asphalt mixture can give more superiority compared to asphalt mixture without PET which known as conventional asphalt mixture. Having considered the economic and environmental prudent angles, utilization of PET as an additive to asphalt mixture is suitable to be used for road pavement.

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